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MELBOURNE, VICTORIA

Flight Mechanics Technical Memorandum 420

FLUID DYNAMIC CHARACTERISTICS OF AN UNDERWATER TOWED SOUND GENERATOR

by

C. Jermey

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FLUID DYNAMIC CHARACTERISTICS OF AN UNDERWATER TOWED SOUND GENERATOR

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C. Jermey

SUMMARY

An underwater towed sound generator, used in sonar research work, was found to be unstable when under tow. This document records wind tunnel tests carried out on a model of the towed vehicle. Investigations were concerned mainly with static stability characteristics and the effectiveness of various configurational changes in improving the stability of the vehicle. The reasons for the original instability are identified and proposals are presented for some minimal effort modifications to the vehicle to achieve satisfactory towed stability.

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POSTAL ADDRESS: Director, Aeronautical Research Laboratory,
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1. INTRODUCTION

The underwater towed sound generator referred to in this document was designed for use in research on sonar detection systems. It is towed behind a small ship at various speeds and depths and emits a powerful low frequency sound simulating certain submarine noise frequencies. In earlier versions the generator had behaved acceptably under tow, but a design change, incorporating additional equipment into the towed assembly, had resulted in seriously unstable behaviour.

In consultations with Aerodynamic Research Group a likely reason for the unstable behaviour was identified and suggestions advanced for corrective measures. The wind tunnel tests reported here were then carried out to measure the fluid dynamic characteristics of the existing shape and to assess the effectiveness of selected modifications intended to improve the towing stability.

2. EXPERIMENTAL DETAILS

2.1 Experimental equipment

The wind tunnel models used are shown in figure 1, where the dimensions refer to the models, made to a scale of 1/10 relative to the full size vehicle. The actual vehicle consists of a nose section followed by a pressure compensation system, the sound source and then a group of air bottles, all supported by an external strongback and enclosed within a cylindrical fibreglass sheath. The strongback contains a row of holes (shown in figure 1c) which allow for the attachment of the towline at a wide range of axial positions. The geometry of the wind tunnel models duplicates the actual vehicle in all critical dimensions, but lacks some detail in that several small bolt heads, slots and access holes are not modelled. Because of the bluff nature of this shape these omissions were not expected to cause any serious errors in the results.

The derivation of the somewhat unusual tail designs shown in figure 1 stems from practical constraints on the design and operation of the actual vehicle. To satisfy these constraints the tail designs have to:

(i) produce sufficient pitching moment to make the vehicle statically stable.

(ii) be simple to manufacture and fit, requiring minimal modification to the existing body structure.

(iii) allow the use of the existing deck cradle and winch system with minimal modifications.

(iv) be robust enough to withstand collision with the ship structure during deployment and recovery operations.

(v) be of minimal hazard to personnel who may fall against the tail assembly during normal shipboard operations.

The tail designs shown in figure 1 were deemed to be the most likely to satisfy all of these constraints.

All the wind tunnel tests were carried out with the model mounted on a six component strain gauge sting balance in the 360mm x 380mm slotted working section of the continuous flow wind tunnel S1 at the Defence Science and Technology Organisation, Salisbury.

2.2 Experimental procedure

The wind tunnel test procedure followed a standard static force and moment measurement programme, covering the conditions listed below:

Mach number	0.35
Reynolds number	0.34×10^6 (based on diameter)
Incidence	$-30°$ to $30°$
Sideslip	$-30°$ to $30°$

3. PRESENTATION AND DISCUSSION OF RESULTS

All results are given in the body fixed axis system shown in figure 2. No corrections have been included for blockage or wall interference. However, for this essentially low-lift shape in a slotted working section these errors should not be significant.

The force and moment data presented in this document are a limited selection from the full six component data which were measured. The full data are available and may be obtained by contacting the author.

3.1 Quality of the simulation

The wind tunnel test conditions differ from the full scale conditions in two possibly significant features.

The full scale conditions are; incompressible flow (ie Mach number approaching zero) and Reynolds numbers of about 0.4 to 1.1×10^6, as compared to the test conditions of Mach 0.35 and a Reynolds number of 0.34×10^6.

For free stream Mach numbers below 0.5 compressibility effects are generally small and a good approximation can be calculated from the Prandtl-Glauert Rule which states that:

$$C_{x_{(M=0)}} = C_{x_M} \sqrt{(1-M^2)}$$

where, M = Mach number

C_{x_M} = aerodynamic coefficient at Mach number of M

$C_{x_{(M=0)}}$ = aerodynamic coefficient at Mach number of 0

Results given in this report have therefore been corrected for compressibility effects by the application of this factor (which for Mach 0.35 evaluates to 0.937).

To determine the effect of Reynolds number on the measured results a limited series of tests was carried out over a range of Reynolds numbers from 0.08 to 0.43×10^6. Figure 3 shows the magnitude of the variation in the normal force coefficient, with respect to results obtained at a Reynolds number of 0.43×10^6. Although the variation is fairly large at low

Reynolds numbers, figure 3 shows that the rate of variation becomes considerably less as the Reynolds number increases. Extrapolation of these curves suggests that results obtained at the normal test Reynolds number of 0.35×10^6 will be representative of full scale conditions, with maximum errors of no more than about 4 percent.

Taking all sources of error into consideration it is concluded that the results given here represent a valid model of the characteristics of full scale vehicles in operational use, with a typical uncertainty level of about 5%.

3.2 Characteristics of the original unmodified vehicle

Figure 4 shows a selection of results illustrating the stability characteristics of the original vehicle. The slopes of the pitching and yawing moment curves (figure 4a and b) show that the vehicle is clearly unstable in both incidence and sideslip planes. In addition, figure 4c shows that sideslip excursions produce surprisingly large induced rolling moments, due to asymmetries in the crossflow over the body caused by the strongback. The overall conclusion is that the dangerously unstable behaviour of the full scale vehicle as observed under tow is not surprising.

3.3 Effect of add-on tail units

Figure 5 shows again the characteristics of the unmodified vehicle, this time plotted together with the results obtained with the add-on tail units. Figure 5a, b, c and d show that with either tail the vehicle is statically stable, tail 3 producing the highest static margin. Stability in the sideslip plane is clearly the more critical quantity, due to the need to overcome the destablising yawing moment generated by the strongback.

Note that the results given here assume a reference centre (centre of mass) which is unchanged from the tail-off to the tail-on configurations, whereas unless ballast were added to the nose of the vehicle to counterbalance the tail mass, the centre of mass would actually be further rearward for the tail-on configurations. With an all-aluminium tail construction this rearward shift would be about 0.3 calibers for tail 1, and 0.25 calibers for tails 2 and 3. Even allowing for this shift, all tail configurations remain stable, although the static margin in the sideslip plane could be considered marginal for tail 2.

Figure 5e shows that the add-on tail units have a large effect on the sideslip induced rolling moment, generally reducing its magnitude. The induced rolling moment peaks rather higher for tail 3 than for either other tail, but this should not create a problem since under tow sideslip angles should not reach more than a few degrees.

Figure 5f shows the effect of the tail units on the drag coefficient of the vehicle. Interestingly, although tail 3 is considerably larger than tail 2 and generates substantially larger stabilising moments, its drag is almost identical. This is because the cylindrical fins of tail 3 are of thinner material than those of tail 2, thus reducing the pressure drag component, which is the dominant drag producing mechanism for these non-streamlined tail shapes.

3.4 Effect of nose shape variation

Figure 6 summarises the effect of the flat nose on the fluid dynamic characteristics of the vehicle with tail 1 attached. Figure 6a and b shows that the flat nose produces only very small changes in the incidence and sideslip plane stability. These changes generally reduce stability at low attitudes and are therefore not desirable.

The only significant effect of the flat nose shape is to produce a large increase in drag. Figure 6c shows that the flat nose produces a drag increment of about 50% over the original nose.

3.5 Effect of the strongback

Figure 7 compares results from tests with no strongback, the cut-down strongback and the full strongback, all with tail 1. Figure 7a, b and c shows that the strongback has very little effect on the incidence plane stability, but does significantly reduce the sideslip plane stability. Removal of the forward portion of the strongback produces a marked improvement but still falls short of the stability level with no strongback.

Figure 7d shows that the strongback is the cause of the induced rolling moment coefficents, and that removal of the forward portion of the strongback produces a slight reduction in these rolling moments.

Figure 7e shows the contribution of the strongback to the drag coefficient of the vehicle.

3.6 Characteristics of the best performers

'Best' is here taken to mean the most stable two configurations, which consist of the original nose and body with the cut-down strongback and either tail 1 or tail 3. Figure 8 summarises the characteristics of these two configurations. Generally there is little to choose between them but tail 3 does appear to offer slightly greater stability and lower drag.

4. CONCLUDING REMARKS

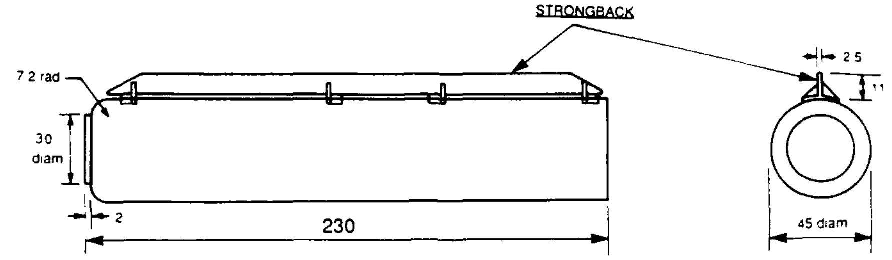
(1) The original unmodified vehicle is shown to be statically unstable in both incidence and sideslip planes, and to exhibit significant sideslip induced rolling moments.

(2) Any of the three add-on tail units described here should make the vehicle statically stable. Tails 1 and 3 exhibit very similar characteristics and both perform significantly better than tail 2.

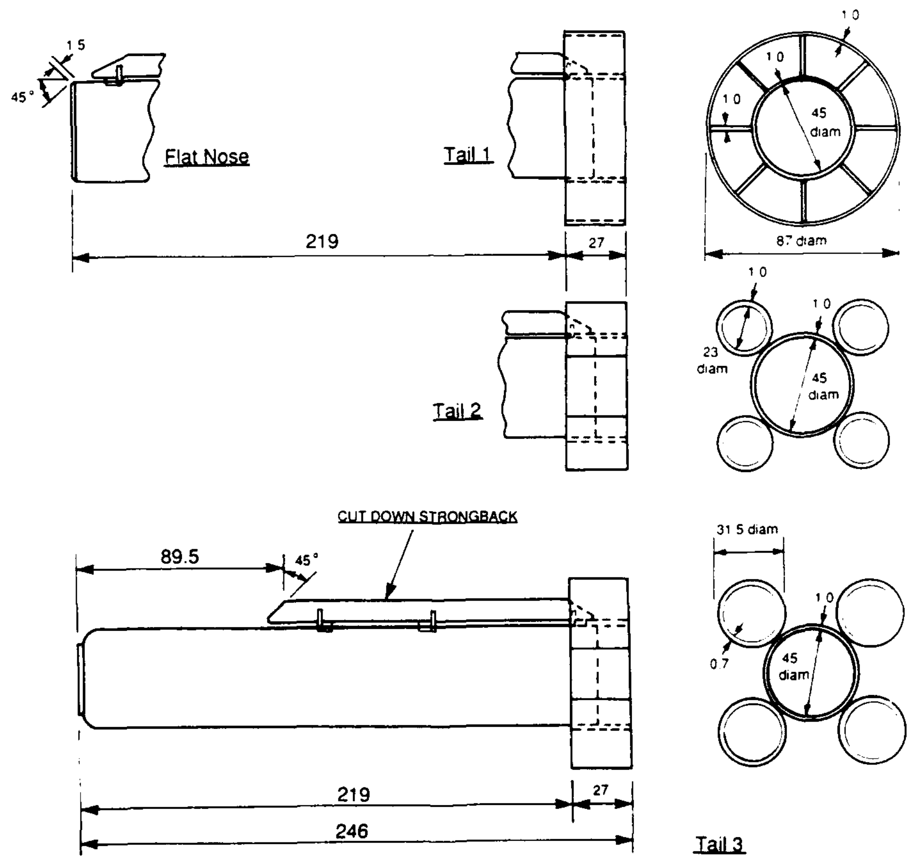
(3) The use of a flat nose shape produces no measurable gain in stability, its only significant effect being a large increase in drag.

(4) The external strongback is shown to be a generally undesirable fluid dynamic feature. Its major effects are to significantly reduce stability in the sideslip plane and to generate some unusual induced rolling moments. By removing the forward portion of the strongback these undesirable effects can be reduced but not removed. With an appropriate tail unit attached, however, these effects should not be a problem.

(5) A recommended vehicle configuration would consist of the original nose, the cut-down strongback, and either tail 1 or tail 3. Performance with either tail is similar, but tail 3 appears to be slightly superior.



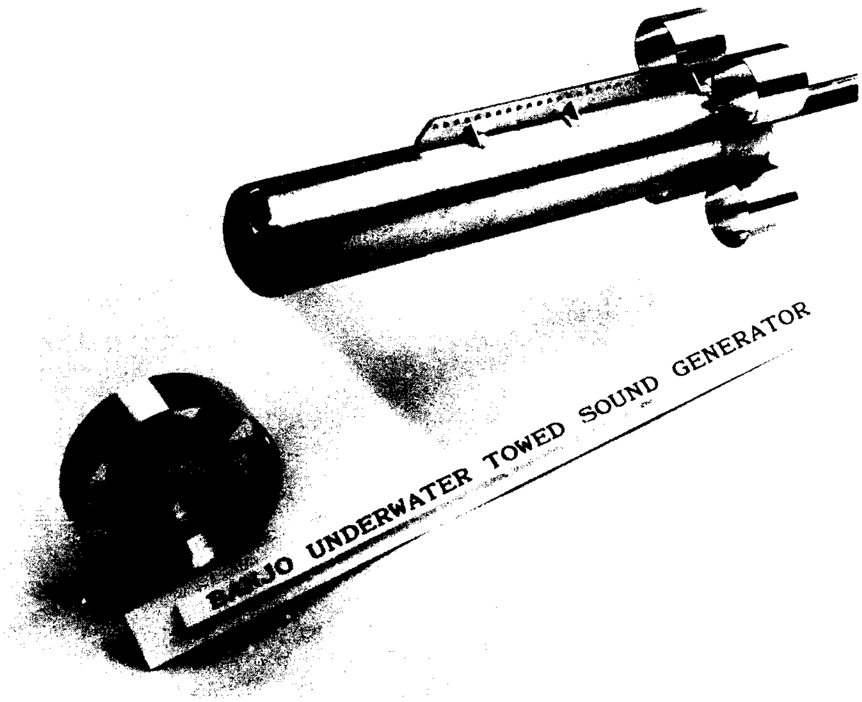
(a) Original unmodified shape



Note: All dimensions in mm

(b) Proposed modifications

FIGURE 1: WIND TUNNEL MODELS



c) Model shown with original nose, cut-down strongback and tail 3,
tail 1 shown separated from model

FIGURE 1. CONT'D: WIND TUNNEL MODELS

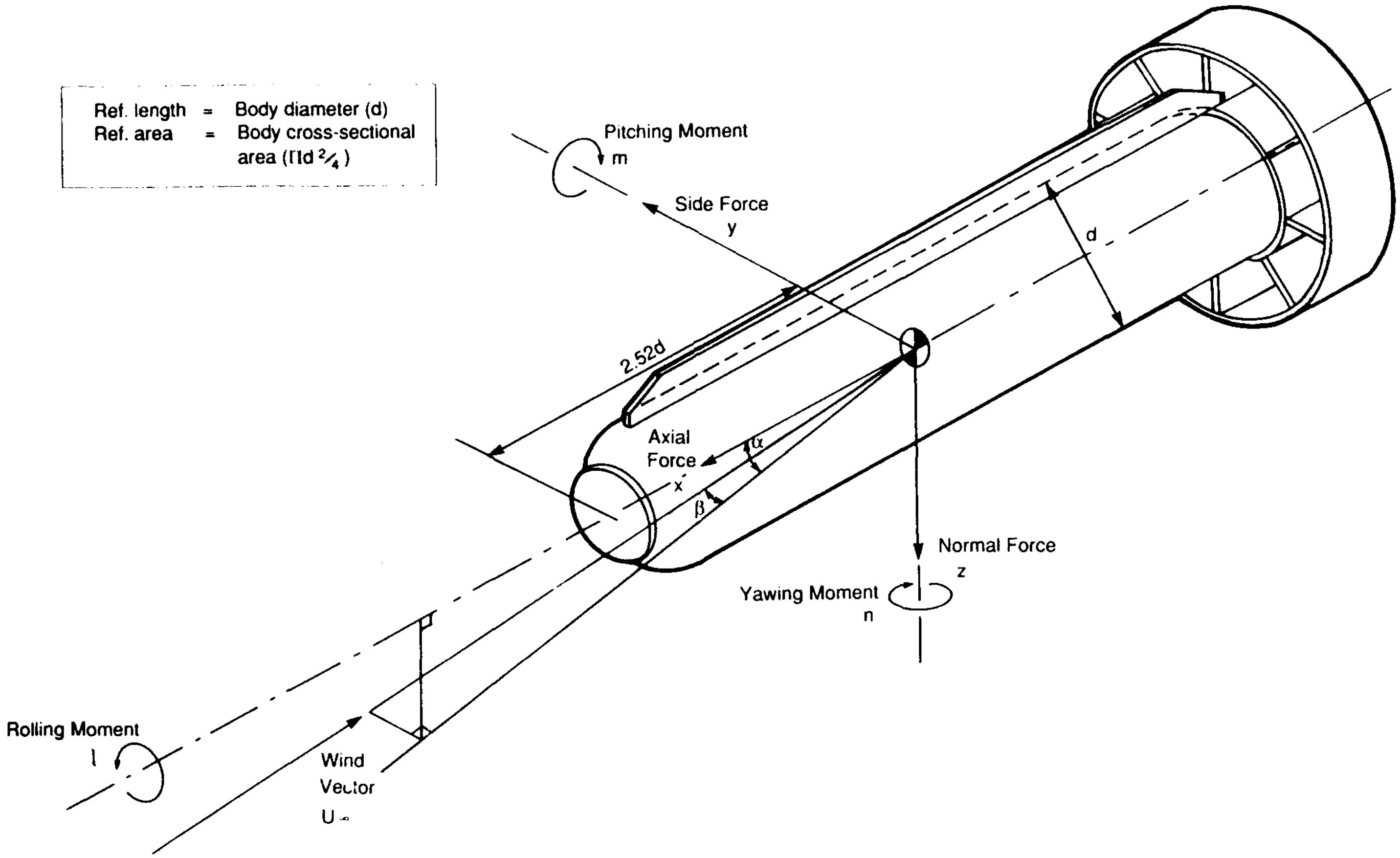


FIGURE 2: AXIS SYSTEM USED FOR PRESENTATION OF RESULTS

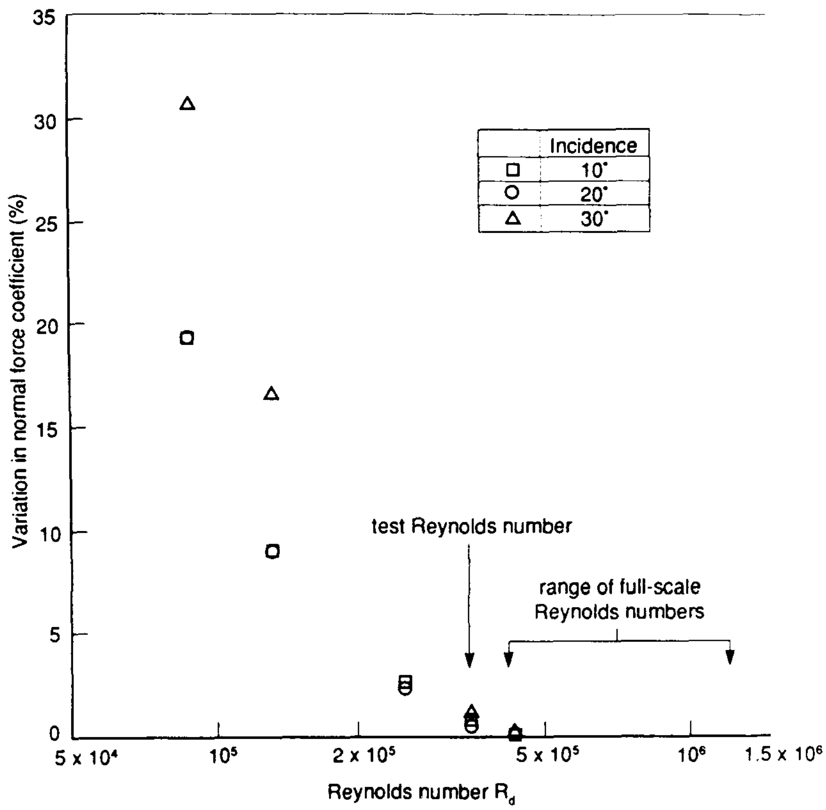
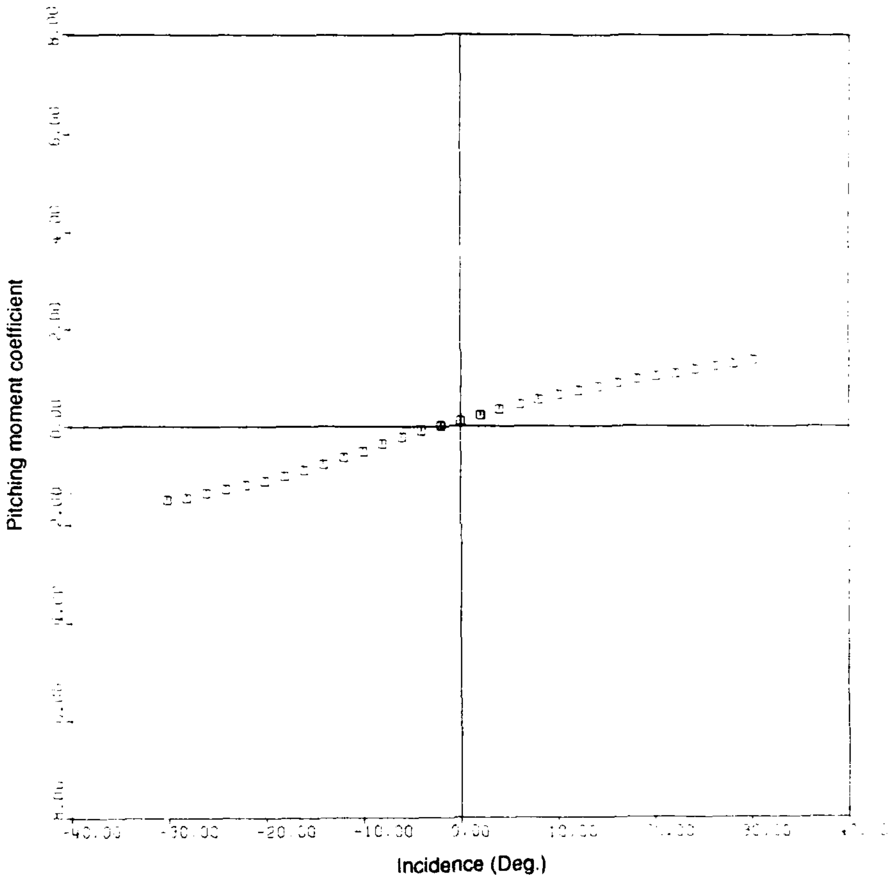
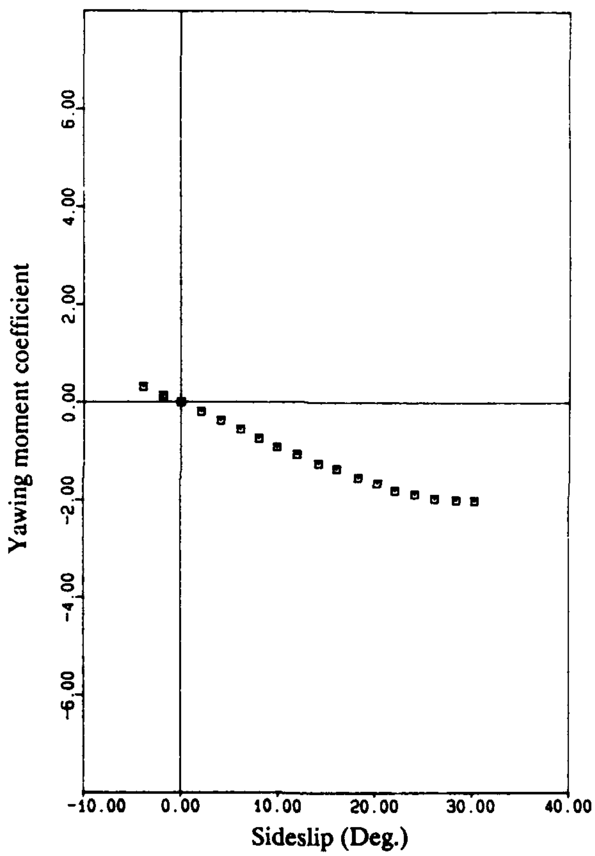


FIGURE 3: EFFECT OF SUB-SCALE REYNOLDS NUMBER, CONFIGURATION IS: BODY + ORIGINAL NOSE + STRONGBACK + TAIL 1



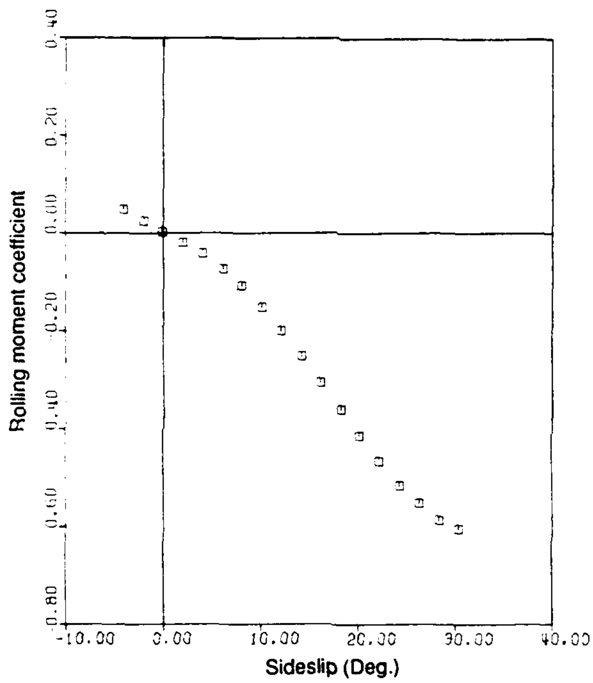
a) Pitching moment coefficient

FIGURE 4. CHARACTERISTICS OF THE ORIGINAL VEHICLE,
CONFIGURATION IS BODY + ORIGINAL NOSE + STRONGBACK



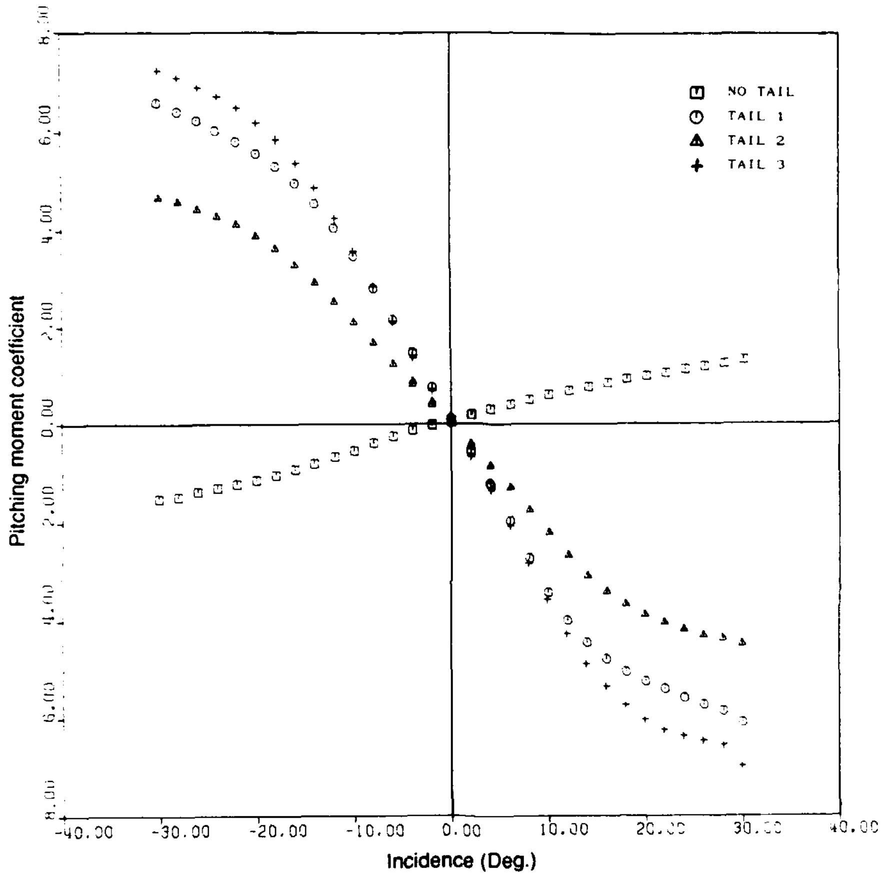
b) Yawing moment coefficient

FIGURE 4. CONT'D: CHARACTERISTICS OF THE ORIGINAL VEHICLE,
CONFIGURATION IS BODY + ORIGINAL NOSE + STRONGBACK



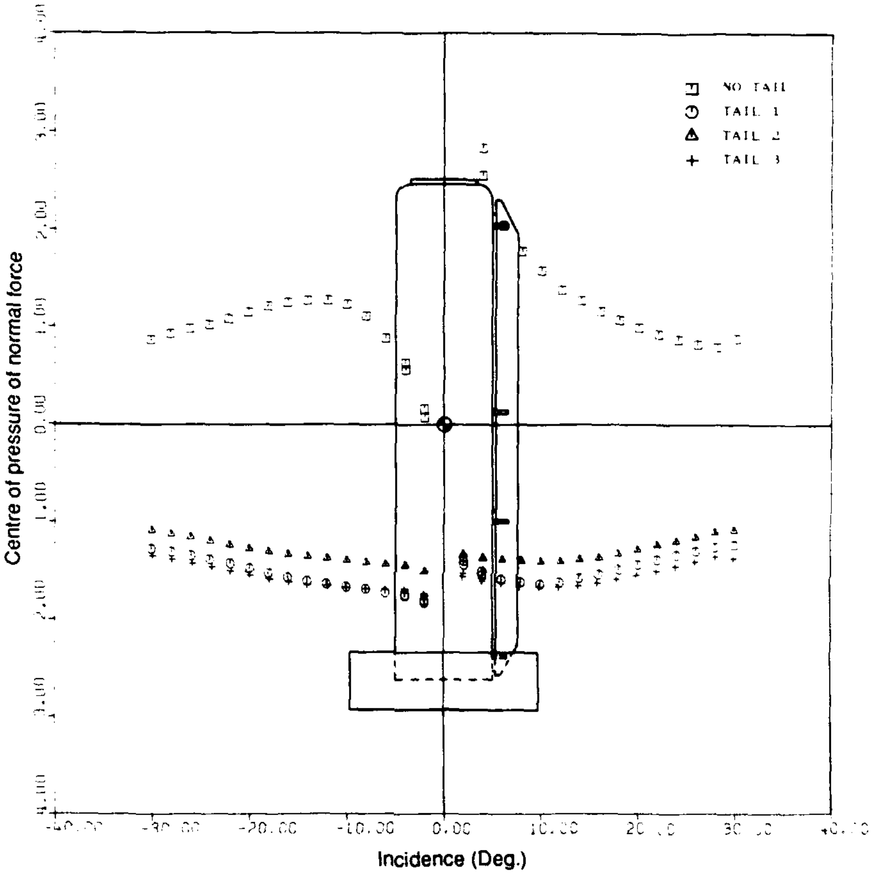
c) Rolling moment coefficient

FIGURE 4. CONT'D: CHARACTERISTICS OF THE ORIGINAL VEHICLE,
CONFIGURATION IS BODY + ORIGINAL NOSE + STRONGBACK



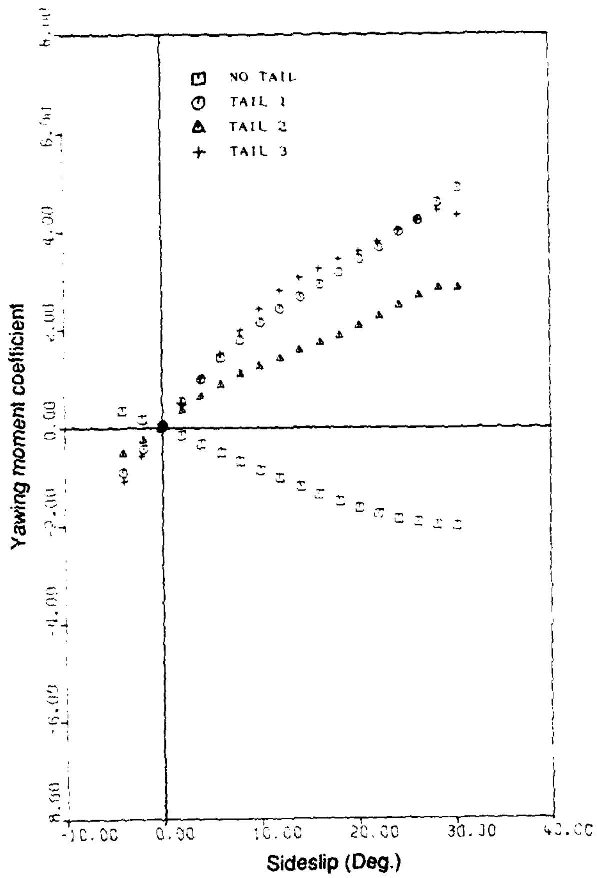
a) Pitching moment coefficient

FIGURE 5. EFFECT OF ADD-ON TAIL UNITS
CONFIGURATION IS BODY + ORIGINAL NOSE + STRONGBACK



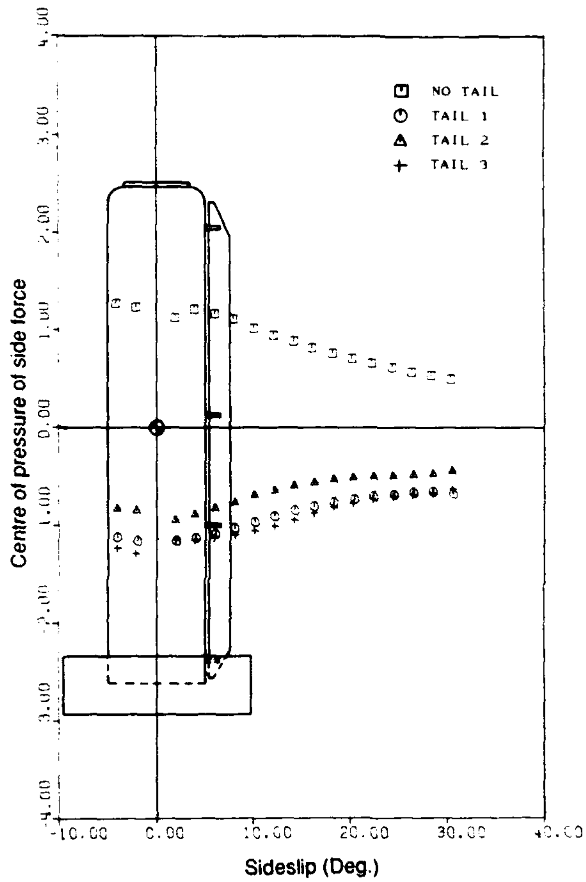
b) Centre of pressure of normal force

FIGURE 5. CONT'D: EFFECT OF ADD-ON TAIL UNITS
CONFIGURATION IS BODY + ORIGINAL NOSE + STRONGBACK



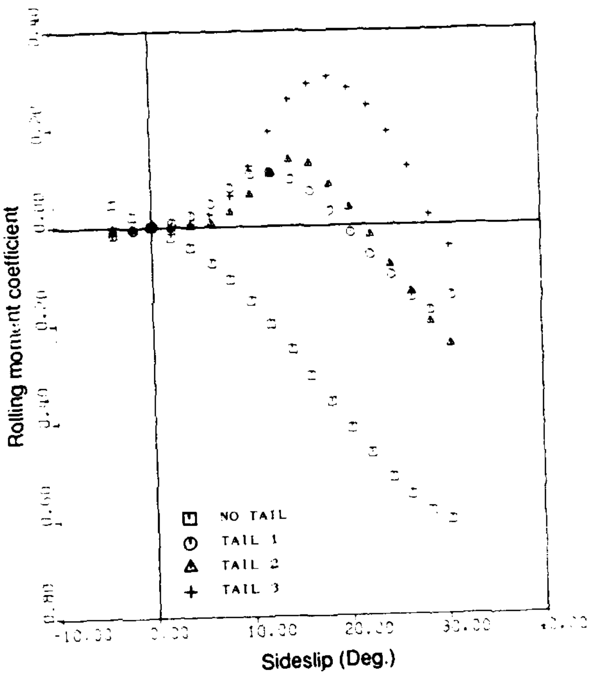
c) Yawing moment coefficient

FIGURE 5. CONT'D: EFFECT OF ADD-ON TAIL UNITS
CONFIGURATION IS BODY + ORIGINAL NOSE + STRONGBACK



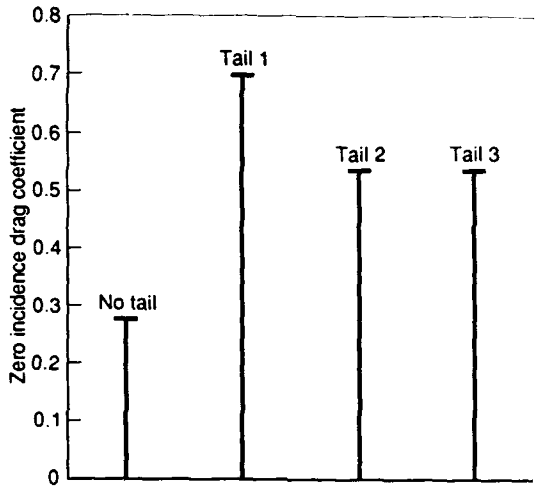
d) Centre of pressure of side force

FIGURE 5. CONT'D: EFFECT OF ADD-ON TAIL UNITS
CONFIGURATION IS BODY + ORIGINAL NOSE + STRONGBACK



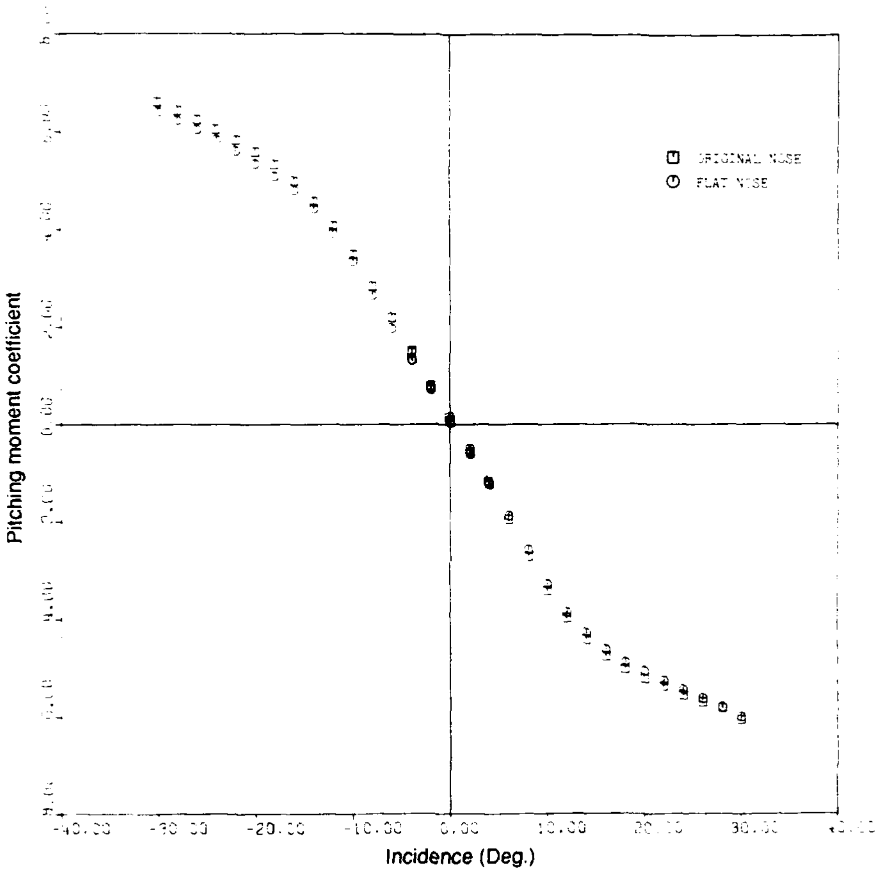
e) Rolling moment coefficient

FIGURE 5. CONT'D: EFFECT OF ADD-ON TAIL UNITS
CONFIGURATION IS BODY + ORIGINAL NOSE + STRONGBACK



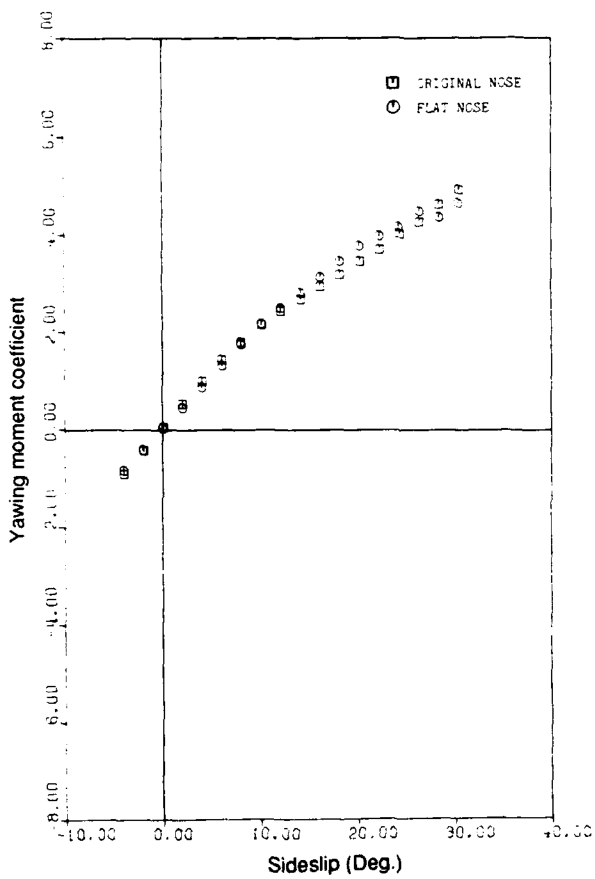
(f) Zero incidence drag coefficient

FIGURE 5 (CONT'D): EFFECT OF ADD-ON TAIL UNITS, CONFIGURATION IS:
BODY + ORIGINAL NOSE + STRONGBACK



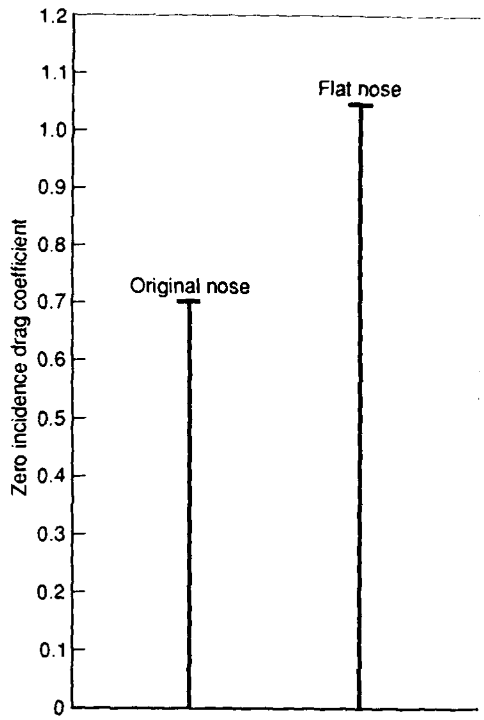
a) Pitching moment coefficient

FIGURE 6. EFFECT OF NOSE SHAPE,
CONFIGURATION IS BODY + STRONGBACK + TAIL 1



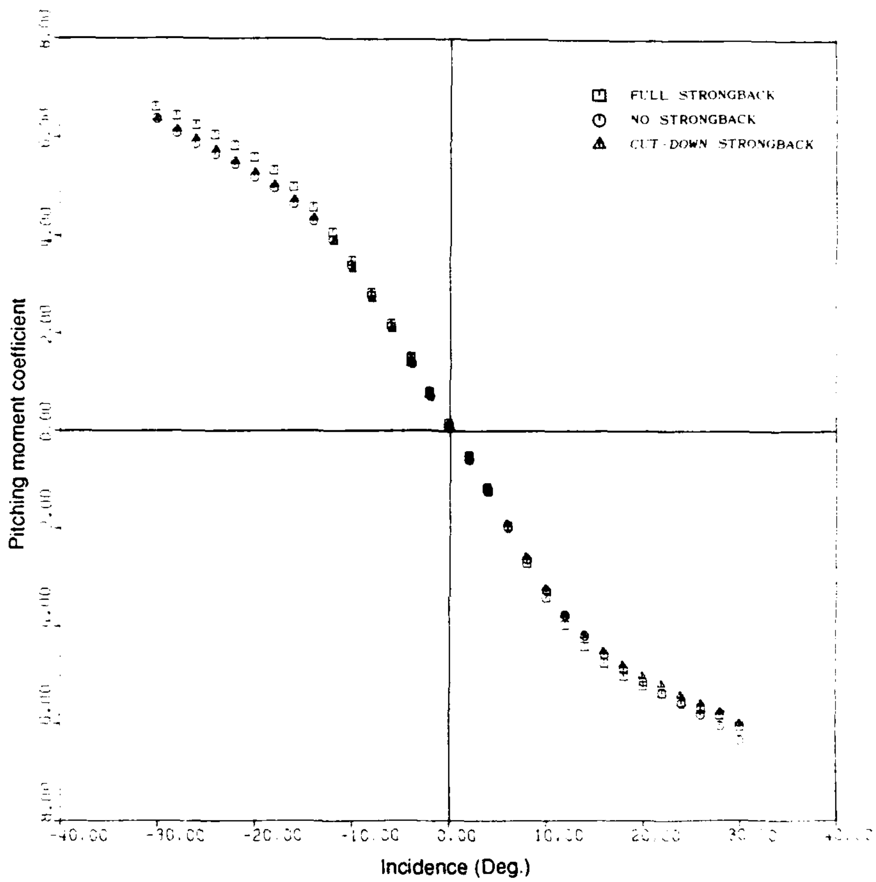
b) Yawing moment coefficient

FIGURE 6. CONT'D: EFFECT OF NOSE SHAPE,
CONFIGURATION IS BODY + STRONGBACK + TAIL 1



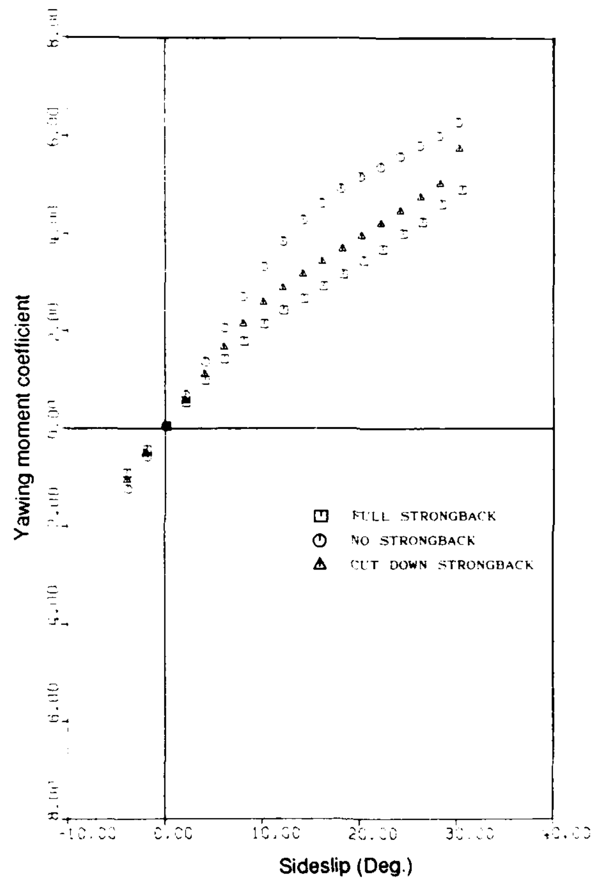
(c) Zero incidence drag coefficient

FIGURE 6 (CONT'D): EFFECT OF NOSE SHAPE, CONFIGURATION IS: BODY + STRONGBACK + TAIL



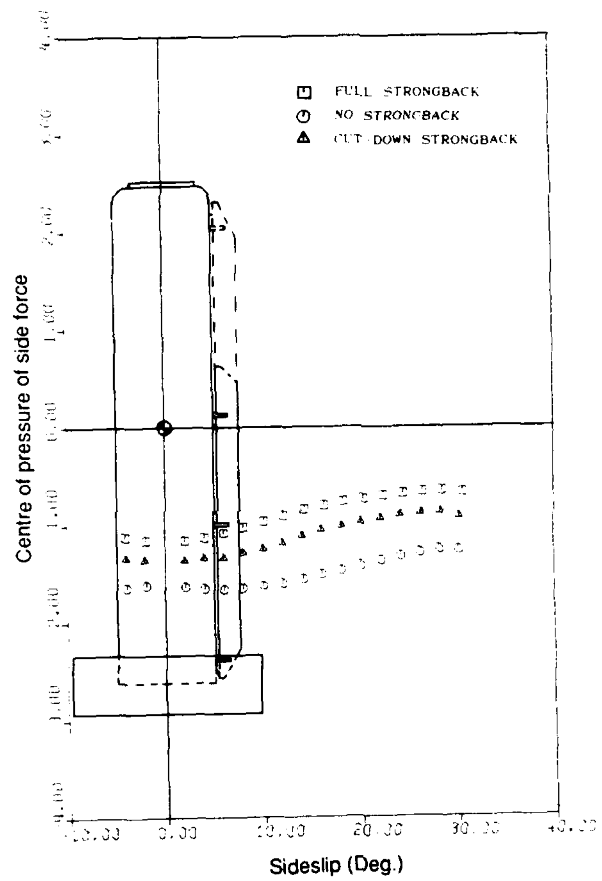
a) Pitching moment coefficient

**FIGURE 7. EFFECT OF STRONGBACK,
CONFIGURATION IS BODY + ORIGINAL NOSE + TAIL 1**



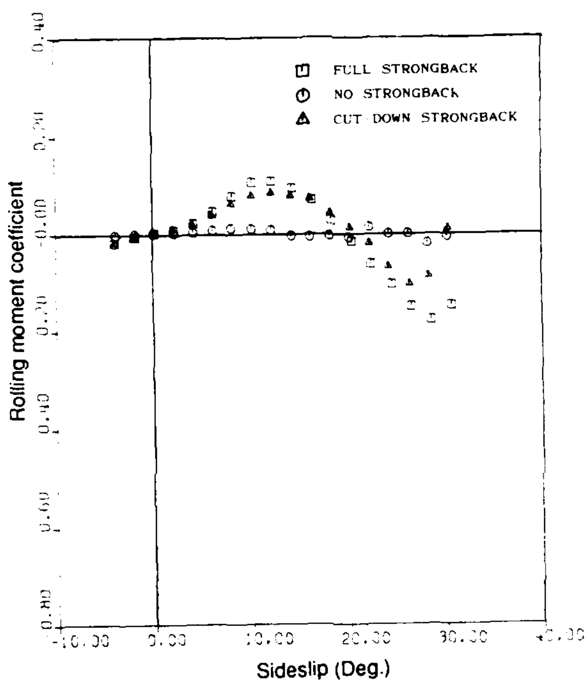
b) Yawing moment coefficient

FIGURE 7. CONT'D: EFFECT OF STRONGBACK,
CONFIGURATION IS BODY + ORIGINAL NOSE + TAIL 1



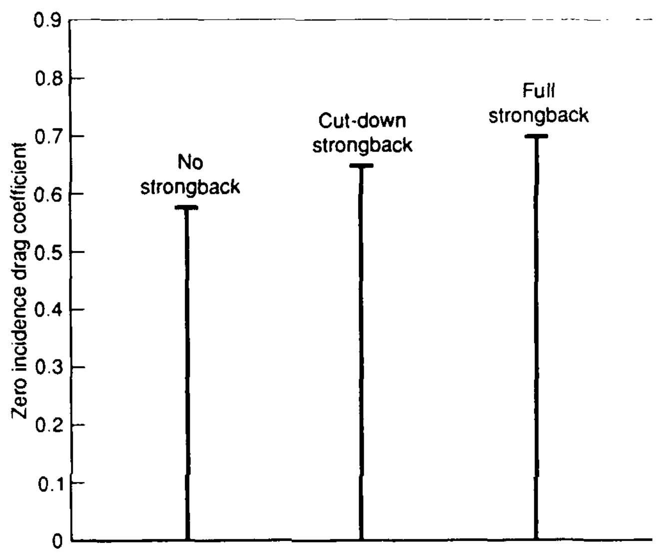
c) Centre of pressure of side force

FIGURE 7. CONT'D : EFFECT OF STRONGBACK,
CONFIGURATION IS BODY + ORIGINAL NOSE + TAIL 1



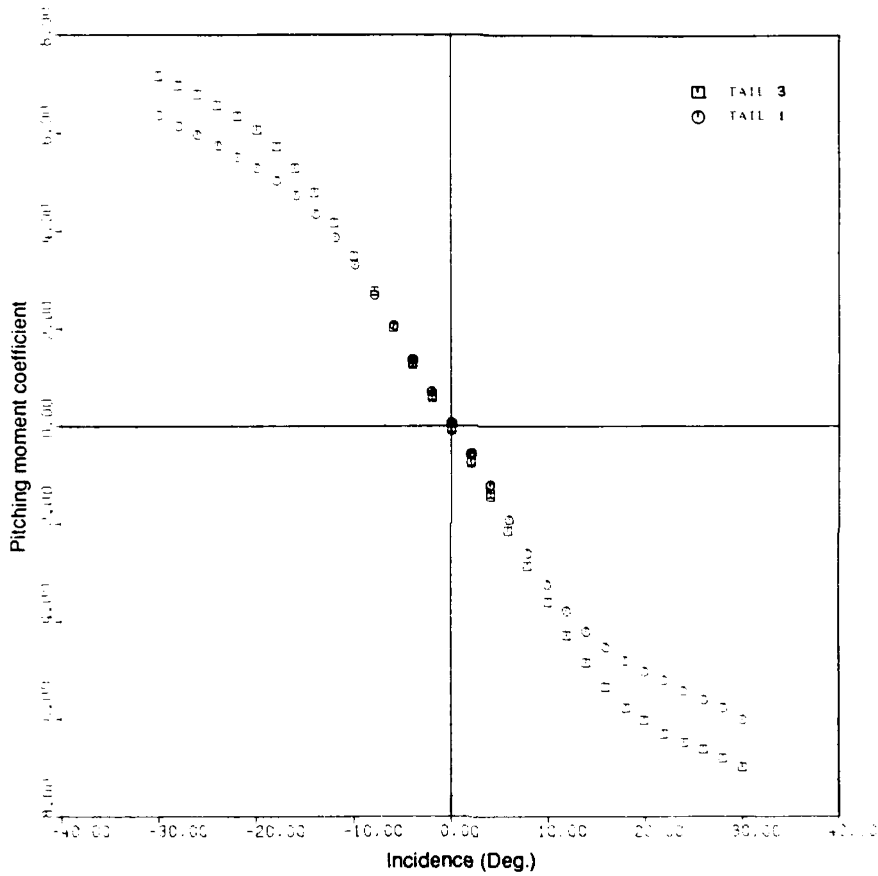
d) Rolling moment coefficient

FIGURE 7. CONT'D: EFFECT OF STRONGBACK,
CONFIGURATION IS BODY + ORIGINAL NOSE + TAIL 1



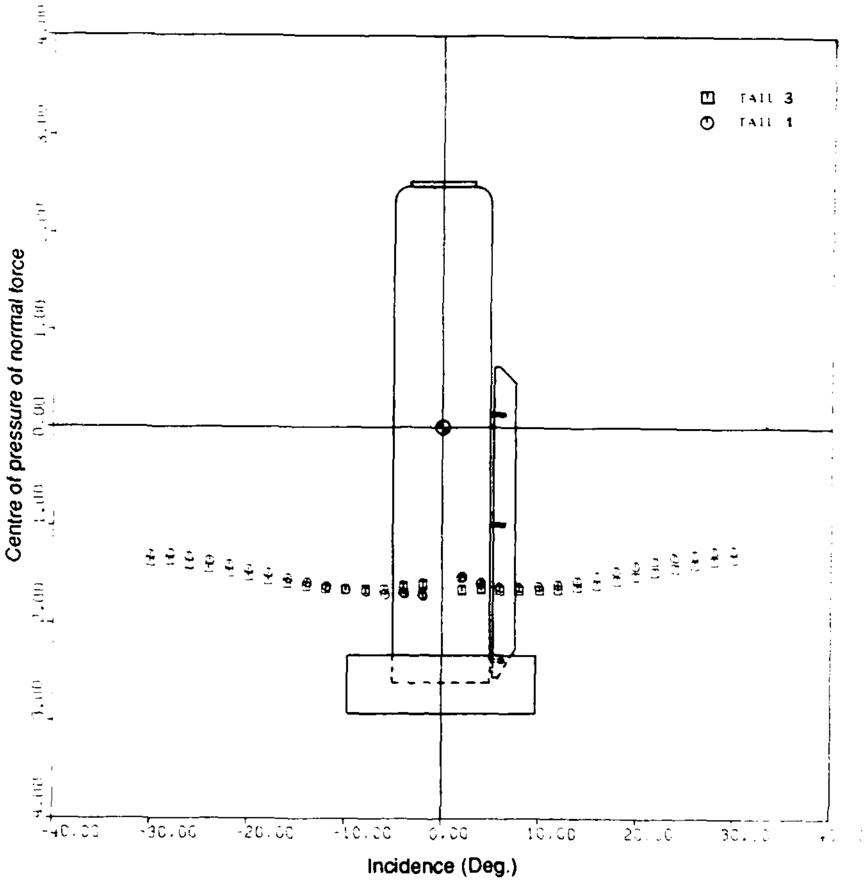
(e) Zero incidence drag coefficient

FIGURE 7 (CONT'D): EFFECT OF STRONGBACK, CONFIGURATION IS:
BODY + ORIGINAL NOSE + TAIL 1



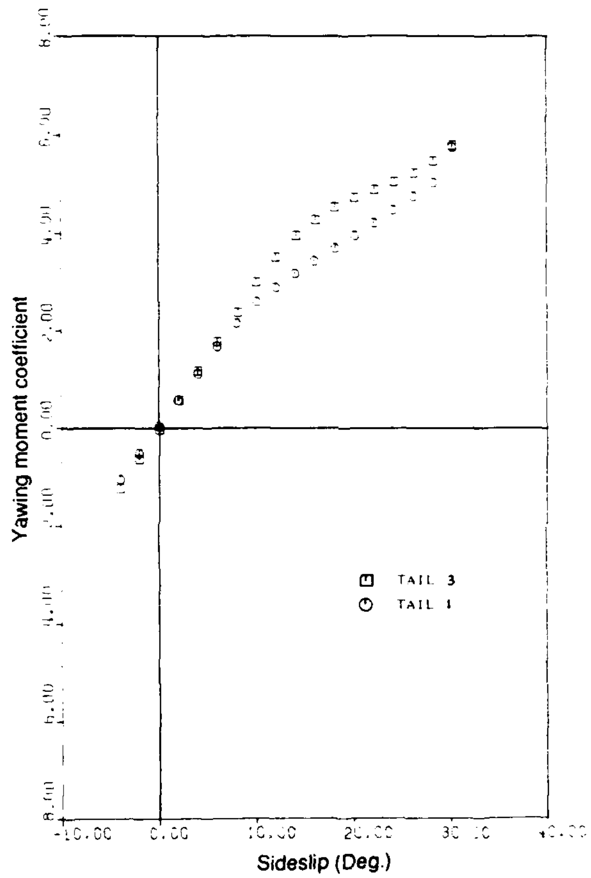
a) Pitching moment coefficient

FIGURE 8. CHARACTERISTICS OF THE BEST PERFORMERS, CONFIGURATION IS BODY + ORIGINAL NOSE + CUT-DOWN STRONGBACK



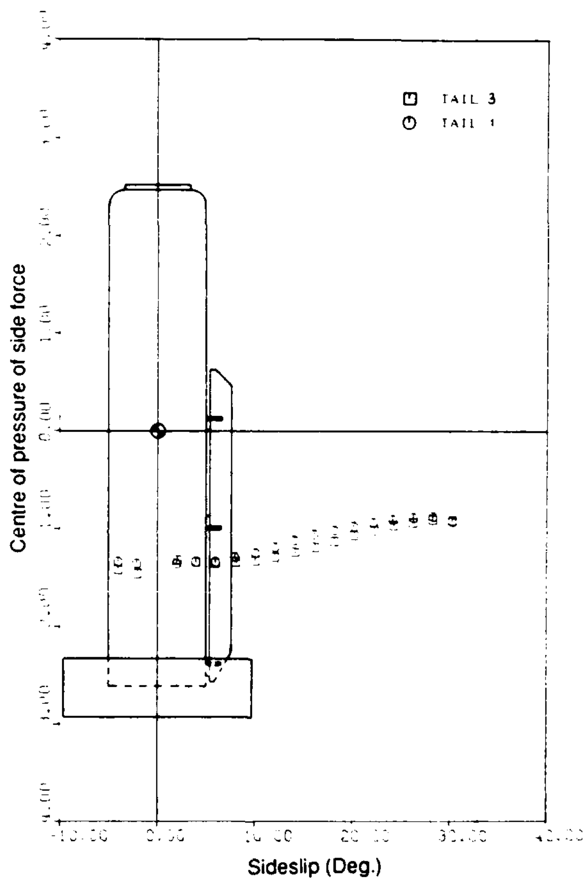
b) Centre of pressure of normal force

FIGURE 8. CONT'D: CHARACTERISTICS OF THE BEST PERFORMERS, CONFIGURATION IS BODY + ORIGINAL NOSE + CUT-DOWN STRONGBACK



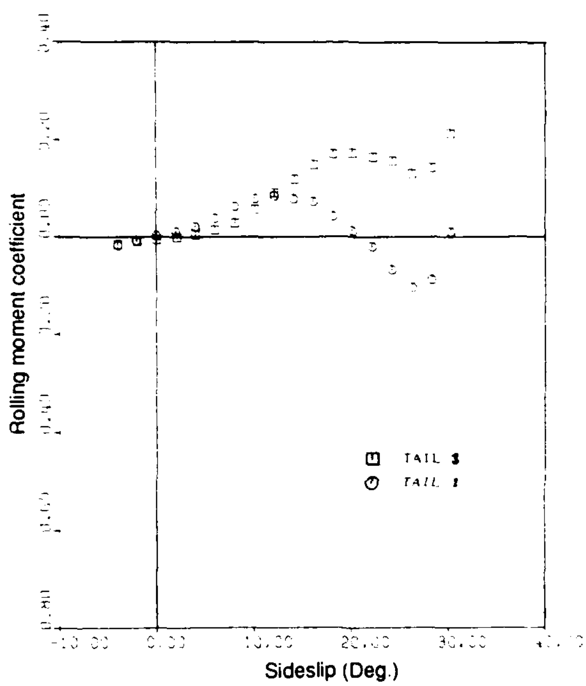
c) Yawing moment coefficient

FIGURE 8. CONT'D : CHARACTERISTICS OF THE BEST PERFORMERS, CONFIGURATION IS BODY + ORIGINAL NOSE + CUT-DOWN STRONGBACK



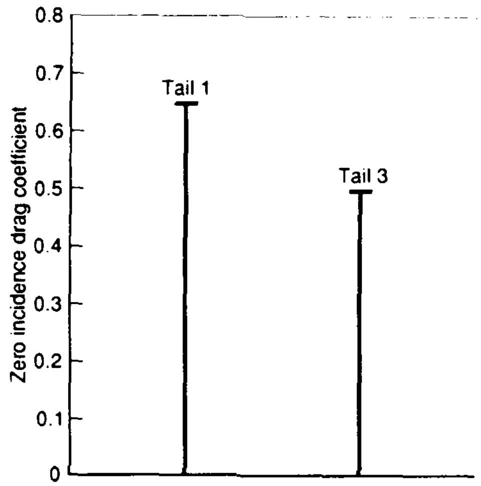
d) Centre of pressure of side force

FIGURE 8. CONT'D: CHARACTERISTICS OF THE BEST PERFORMERS, CONFIGURATION IS BODY + ORIGINAL NOSE + CUT-DOWN STRONGBACK



e) Rolling moment coefficient

FIGURE 8. CONT'D: CHARACTERISTICS OF THE BEST PERFORMERS, CONFIGURATION IS BODY + ORIGINAL NOSE + CUT-DOWN STRONGBACK



(f) Zero incidence drag coefficient

FIGURE 8 (CONT'D): CHARACTERISTICS OF THE BEST PERFORMERS,
CONFIGURATION IS:
BODY + ORIGINAL NOSE + CUT-DOWN STRONGBACK

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16. ABSTRACT
An underwater towed sound generator, used in sonar research work, was found to be unstable when under tow. This document records wind tunnel tests carried out on a model of the towed vehicle. Investigations were concerned mainly with static stability characteristics and the effectiveness of various configurational changes in improving the stability of the vehicle. The reasons for the original instability are identified and proposals are presented for some minimal effort modifications to the vehicle to achieve satisfactory towed stability.

Keywords!

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16. ABSTRACT (CONT).

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